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Enhancing Pathways From Community Colleges to Four-Year Schools With a Circuits Course and Lab for Distance Students

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Enhancing Pathways from Community Colleges to Four-Year Schools with an Online Lecture/Laboratory Course in Circuits

Introduction

At the University of Idaho, an intermediate circuits course is required before students can take junior-level classes. However, most community colleges only offer a first course in circuits, so transfer students are immediately behind in their academic progression. One way to address this is to develop an online lecture course with a suite of labs that a student can perform before coming to the university, say over the summer, so that the student can be on-track for graduation. In addition, as the number of online courses grows, these labs can be used by students who cannot come to campus.

In our curriculum, the intermediate electrical engineering lecture and laboratory course begins with sinusoidal sources, then introduces the students to steady-state phasor analysis, complex power, and three-phase power. With an introduction to computer simulation towards the end. The lecture portion of the course would continue onto Laplace and Fourier transforms. The students would meet in a room with benches loaded with equipment and components to perform their laboratory exercises. In the effort to improve the accessibility of the laboratory experience, and with the funding from our state board of education, new equipment was selected for portability and the laboratory procedure was adapted and developed for the new equipment. This includes two new lab exercises, one where the students measure and analyze a three-phase power circuit, and another leveraging the software integration of the equipment for the students to experiment with signals and passive filter circuits.

The equipment and components are compact enough to be easily packed, and transported by or shipped to students so they can perform the exercises at their home. Allowing the students to complete a prerequisite course for their degree path.

Literature Survey

Online lecture courses are widely available in many academic disciplines, including engineering. However, an engineering degree requires a student to take required laboratory courses, which are more problematic to deliver online. Early attempts at online laboratories used the internet to connect a laboratory setup at one location with a student user at another [1]. While a student could perform the experiment remotely, a technician was required to be onsite with the lab setup to repair or resolve any difficulties that arose. Another method of delivering an online lab is to use computer-simulated experiments and online remote-controlled software. Early attempts at this method demonstrated that using multi-media computer experiments along with specially designed hands-on exercises was as effective as teaching engineering laboratory skills as the traditional on-campus lab course [2].

Since these early attempts, a number of different delivery techniques have been developed for online laboratory experiences. These include virtual laboratories [3], which, by necessity, were developed during the Covid-19 pandemic [4], and portable laboratories [5]. Others have developed a laboratory in a box approach [6]. Case studies have been performed to determine the efficacy of virtual/remote labs performed during the pandemic [7]. Recently, this topic has attracted the attention of educators who wish to make engineering laboratories more accessible to a broader range of students [8,9].

Remote Laboratory Platform

In the selection of the lab equipment, the primary considerations were portability, access to equipment, and durability. The options for equipment were to assemble a collection of lab equipment: oscilloscopes, function generators, digital multimeter, LC (Inductance Capacitance) meter, dc supply, and breadboard. Alternatively, National Instruments (NI) and Digilent offer solutions that consolidate the lab into a single item that simplifies the logistics of managing a remote laboratory equipment.

The ELVIS-III from National Instruments provides the necessary lab equipment, and a reasonable user interface with its soft front panels. The lab equipment can be fit into a 19x16x8 inch hard case, with test leads, lab components kit, and a document camera for the station. The hard case provides a durable container for shipping, and a secure location for the lab to be returned to while the student isn't actively working on a laboratory exercise. Lab tools and materials are contained in a multi-compartment parts organizer, stored on the second layer of the case.

Figure 1: Portable lab equipment in travel case. Right: ELVIS-III in the first layer of case. Left: Second layer of case with document camera, cables, organizer with components, and test leads (under organizer).

Each kit includes a document camera, an HD webcam and stand, for assistance purposes. The idea being for students to be able to point the camera at the workspace so the instructor or assistant can see the circuit if the student needs assistance troubleshooting. The camera can also be used during recitation for the student to get help on any of their homework or analysis for their lab reports.

Remote Lab development and Presentation

Managing the student's progression through the materials can be a challenge in a fully remote learning scenario, there is additional consideration for the safety of students and equipment that should be at the forefront of the thought process. Using the online learning management system (LMS), such as Instructure's Canvas, student progress through material can be managed by enforcing required readings, video watching, and minimum score on a quiz written to evaluate critical information. Which should reduce the problems stemming from not fully reading or watching/listening to instructions in the form of a video, or written procedure.

Each laboratory module is broken into 3 parts, shown in Figure 2. First there is an introduction video reviewing the theory used in the lab, demonstrating circuit construction, measurement techniques, and equipment usage. The circuit constructed has the same topology as the one in the exercise, using different component values as not to give away the correct answers, and so the lab procedure can be updated with new components without needing to record a new introduction video. Additionally, the introduction continues to demonstrate analysis using the measurements from demonstration circuit.

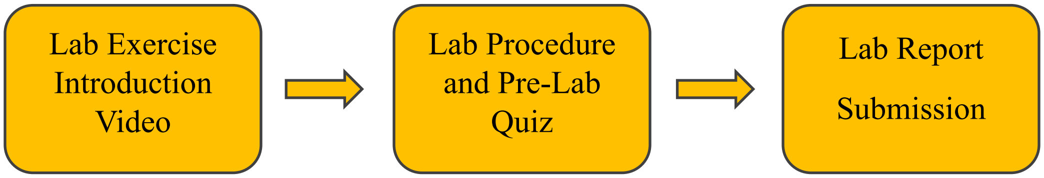

Figure 2: Student progression through each laboratory exercise module.

The introduction video demonstrates the methods needed to complete the laboratory exercise, and the pre-lab quiz verifies the students understanding. Prior to the quiz, the lab procedure is given for students to read, and the introduction video can be rewatched as many times as needed. The quiz is a mix of multiple-choice procedure questions, randomized analysis problems with numeric answers, and a question relating something said during the introduction video to verify the student had watched the introduction through to the end. Afterword the student will perform the exercises, gathering data and performing their analysis, finally submitting their lab report.

Lab topics

For a standard fifteen-week semester, ten laboratory exercises were developed to reinforce the topics from the lecture the laboratory course accompanies. The laboratory exercises, and outcomes are:

1. *Measurements Lab*: Introduction to the ELVIS-III and software.
2. *Measurement of Perodic Waveforms Lab*: Use the equipment to measure period, and amplitude of sinusoid, triangle, and square waveforms. Then calculate RMS amplitude for each.
3. *AC Circuits Lab*: Use the oscilloscope to measure voltage and phase delay, then calculate currents and verify using the digital multimeter.
4. *Phasors Lab I*: Measure elements of a series RLC circuit and analyze results using phasor techniques.
5. *Phasors Lab II*: Measure elements of a series-parallel RLC circuit and analyze the results using phasor techniques.
6. *Complex Power Lab*: Analyze 3 circuits and determine the real and reactive power, then determine and test a resistance value to achieve maximum power transfer for each circuit.
7. *Transformers Lab*: Measure and analyze transformer performance characteristics and compare to the values provided in the datasheet by the manufacturer.
8. *Three-Phase Power Lab*: Log measurements from 7 nodes of a 3-phase series LR circuit with a neutral resistor. Then perform offline analysis of the logged data to determine instantaneous phase and neutral values of voltage and current and total power and produce plots.

9. *Filtering and Fourier Analysis Lab*: Use the ELVIS-III to characterize passive filter circuits using Bode Plots. Then use the FFT to analyze the effects of the filters on an arbitrary superposition of sinusoids.
10. *AC Circuits Simulation Lab*: Use LT-SPICE to simulate a series-parallel RLC circuit and compare simulation results to those from previous exercises.

The laboratory exercise topics start with an introduction to the equipment, discussing and practicing with the multimeter, Oscilloscope, and function generator used through the lab course. Each lab builds on the previous, the first lab module is for introducing the equipment, and methods of measuring circuit components and node values for analysis.

The progression of lab topics follows the presentation of information from lecture, and students should have some practice with analysis from homework assignments. Lab exercises were adapted from an existing set of labs, and new labs were developed to take advantage of the new equipment. Starting with the "measurements lab," students are introduced to the equipment, and measurement procedures. The soft front panels of the ELVIS-III platform are different than what most students have used previously.

Following the introduction to the equipment, lab topics progress from periodic waveforms to phasor analysis, to complex power and circuits using transformers. After the initial introduction to the equipment the following six labs followed the original topics and procedures, adapted for the ELVIS-III platform. The final two labs were developed from scratch leveraging the integration and flexibility of the software of the ELVIS-III. A lab exercise using a three-phase inductive-resistive circuit. Node values are measured and recorded with the datalogger included as part of the prototyping board analog inputs and outputs. Figure 3 shows the 3-phase circuit with connections to the datalogger. Students measure a few cycles of the circuit, and the datalogger saves the measurements to a CSV file.

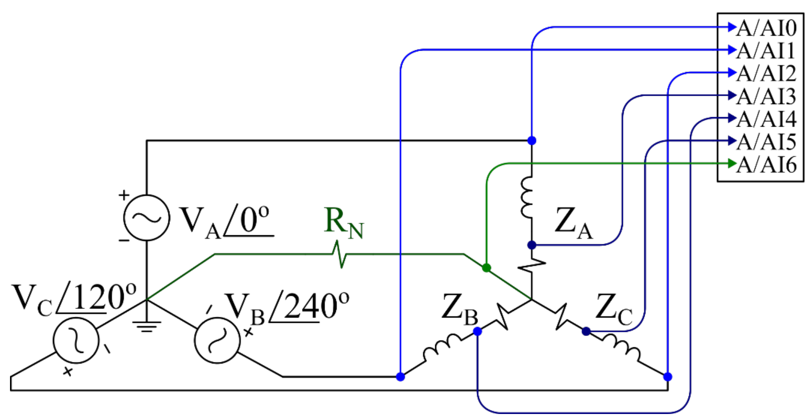

Figure 3: Circuit diagram for 3-Phase lab exercise, with connections to datalogger terminals.

Once the students have the CSV containing their measurements, instructions were given for students to perform analysis of the data using a spreadsheet program and using a general-use math program, students produce plots, similar to the one in Figure 4, and discuss results in their report.

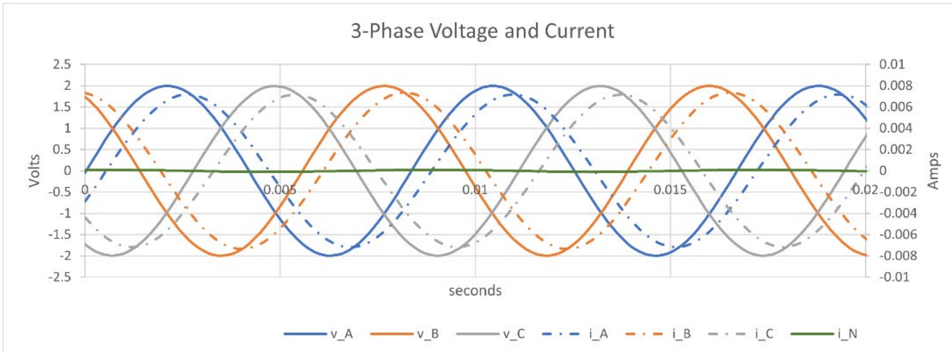

Figure 4: Data plot from 3-Phase experiment.

The Last lab topic using the hardware is a filtering and Fourier analysis exercise, where students build passive filters, then use the arbitrary waveform generator and the Fast Fourier Transform function of the oscilloscope to quantify the effects of the filter, and to compare the relative changes in signal amplitude and phase to the Bode Plot students generated for each of their filters. The arbitrary signal was generated to have signal components within the ranges which low pass, high pass, and band pass filters could be built with the components supplied in the lab parts kit.

The tenth and final lab topic was chosen to use circuit simulation software so the student has time to pack and return the equipment via parcel service and should arrive before the final grades were due for the term.

Student Participation and Feedback

The online laboratory course was offered to a select group of students during a seven-week summer session, who would otherwise require an additional semester to complete their degree program. There were five students in total, four were given an ELVIS kit to take home for the duration of the summer session, and the fifth student was a late addition to the summer enrollment and would come onto campus and use the instructors ELVIS station to complete their lab assignments.

From the survey, we're interested in the students' experience completing the online, questions are tailored at gauging the time required, the equipment, tools, and materials provided to the students for the session. The responses are intended to help determine shortcomings that could be addressed with additional materials or instruction.

The five students who participated in the summer session completed a short survey following the posting of the summer session final grades. Survey questions and participant responses can be found in Appendix A: Student Survey Results . Survey questions are focused on the experience of the online lab, the participants had completed the introductory circuits on-campus and have a more traditional lab to compare their remote experience. The survey questions were:

1. On a scale from 1 to 5, rate your overall online laboratory experience.
2. Were you able to perform the experiments given the instructions and resources provided or did you need extra assistance or materials?
3. Did you spend more or less time on the online laboratory than in-class lab students?
4. On average, how many times did you watch the lab instructional videos?
5. How helpful were the instructors for your online laboratory experience?
6. What was the greatest obstacle to completing the online laboratory?
7. What comments or suggestions do you have about the online laboratory experience? What can be done to improve the experience?

The student responses to the survey generally show the students had a positive view of the course. Figure 5 shows the participants had an acceptable experience or didn't care enough to note the difference.

From question 2, the students reported struggling with the laboratory exercises, or requiring some assistance, but could complete the exercise. When viewed with responses to survey questions 3 and 6, issues with the written procedure and troubleshooting equipment were contributing factors.

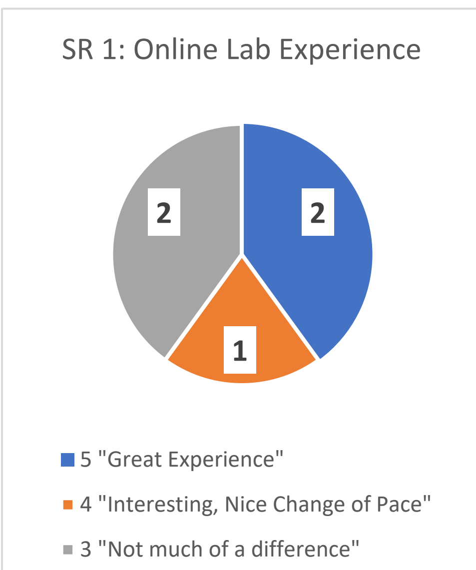

Figure 5: Self-Reported Student Experience, Response options 2 and 1 were not selected by participants.

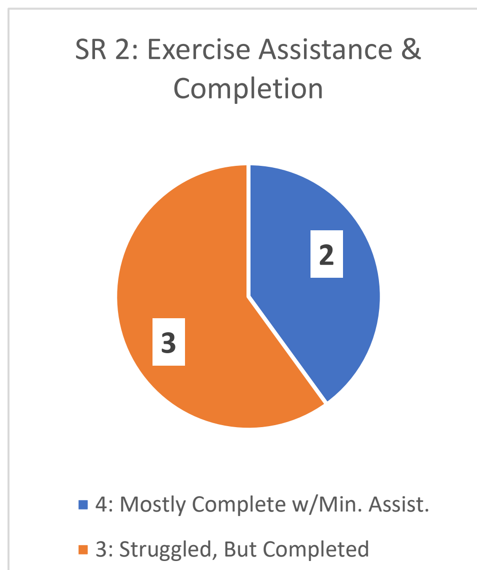

Figure 6: Student completion of lab exercises. Options 5,2, and 1 omitted.

The student responses to the third prompt, summarized in Figure 9, shows that each student spent more time on each exercise. Some factors for the increase in time spent include communication with the instructor or seeking clarification. There are also mentions of troubleshooting equipment and the exercise circuits, with setup time being another factor of the time spent on each exercise.

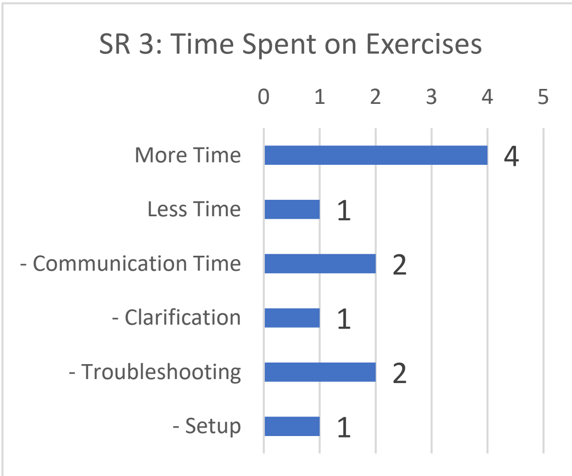

Figure 9: Time students report spending on exercises, with factors mentioned as contributing to the increased time.

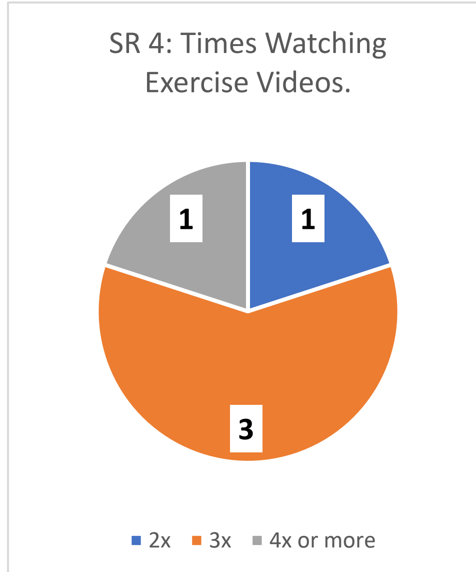

Figure 8: Students report the number of times viewing the laboratory exercise introduction video.

The time spent on each exercise may also correspond to the number of times the student reported viewing the introduction videos, see Figure 8.

Reading the responses to ask about instructor assistance (Figure 7) during the session shows the students value the instructor availability or short response times. Direct or in-person assistance and troubleshooting were valued by participants. The two frequent mentions in the responses to question 6, asking about their perceived obstacles in coursework, were for clarification and instructor assistance (see Figure 10).

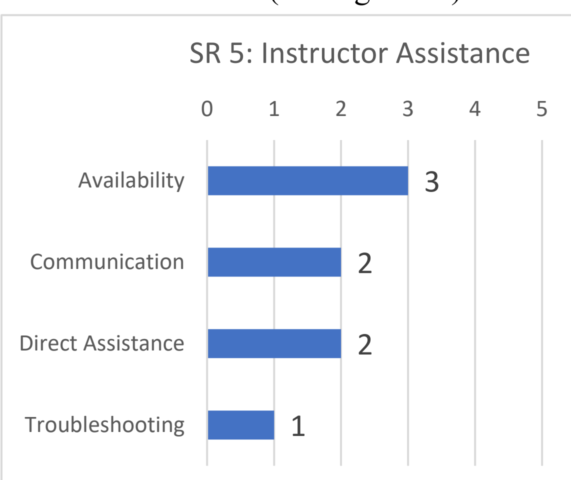

Figure 7: What students reported valued about the assistance they received during the academic session.

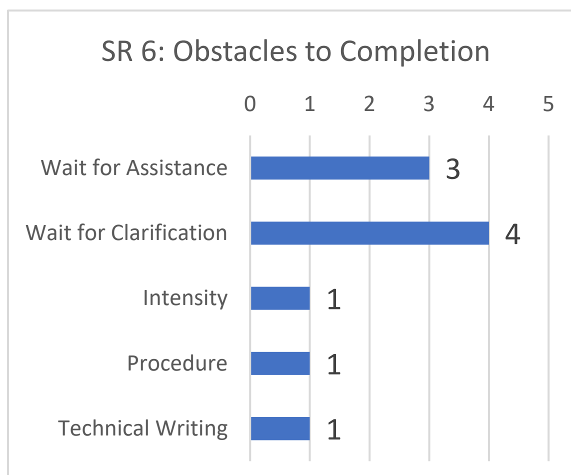

Figure 10: Student reported impediments to completing exercises.

Three takeaways from the survey results that can inform further development of materials would be: First, the remote labs required significantly more time to complete than what the students were used to. There are any number of influences on the students' time, internal and external, conscious and subconscious. The primary reason or solution the students brought up in their responses was instructor availability to answer questions and provide clarification.

Second is to ensure clarity and availability of information. Students usually rewatched the lab instruction videos multiple times. An advantage of recorded information is the ability to rewatch, pause, and change the speed of playback. The responses to survey questions 6 and 7 indicate areas of improvement. One area to improve is the availability of relevant information, since the students are remote a student cannot walk over to the instructor and ask for assistance or clarification. Additional resources in the form of instructional videos for the lab equipment, and written instructions for troubleshooting connectivity issues have been added to the course page.

The final takeaway would be to diligently document all issues that arise with the equipment. The advantage of having lab equipment that is primarily software defined is the flexibility of said equipment. The downside is a general decrease in reliability, and variation between each remote student's experience with the software at the start of the summer session demonstrated the problem with relying on software. A participant responded to question 7 with a positive mention of the in-person sit-down and demonstration of the equipment during the equipment handoff prior to the first lab being helpful.

Conclusions

After the summer session working with the students and developing the course, the viability of offering intermediate lab courses remotely was demonstrated. In addition to the portability of the equipment, the flexibility of the software allowed us to expand the laboratory experience to include physical exercises for three-phase power, Bode plotting, and Fourier analysis. Administering the remote lab course can prove a challenge, but after implementing an enforced progression through lab materials, the problems decreased to questions of clarification and circuit troubleshooting.

The student feedback from the summer session shows that procedure clarity is critical, and instructors should examine their assumptions of what students know have when writing procedures for remote lab exercises. Considerations should also be made for how much time each exercise will take, what may be a fifty minute exercise in an on-campus lab could easily extend to several hours for the remote student.

Changes could include breaking down an exercise procedure into smaller, less overwhelming parts, that can be completed in fifteen to twenty minutes. Alternatively, a shorter introduction and exercise procedure video, with additional short videos explaining specific parts of the procedure for more involved or complicated procedures. Finally having a scheduled meeting or recitation for the students to work on their labs and have immediate access to assistance could be part of the course schedule in future iterations.

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Appendix A: Student Survey Results

**Any names or affiliations have been removed from student responses. Replaced with [inst. <last initial>], or [University]

Non-Numeric responses have been summarized with sentiments, used for visualization. Sentiments are in bold parentheses, "**(...)**", after the response.

1. On a scale from 1 to 5, rate your overall online laboratory experience.

5. Yes, absolutely. Great experience
4. Yeah, it was interesting, a nice change of pace
3. Maybe, didn't notice much difference
2. Uh, only if I had to
1. No way, no how

Responses: 5, 5, 4, 3, 3

2. Were you able to perform the experiments given the instructions and resources provided or did you need extra assistance or materials?

5. I could do everything by myself after following the instructions
4. I mostly could get through the experiment with a little help
3. I struggled a little, but was able to complete the experiments
2. I needed a lot of help from the instructor to complete the experiments
1. I was completely lost and could not finish the experiments

Responses: 4, 4, 3, 3, 3

3. Did you spend more or less time on the online laboratory than in-class lab students?

I think that I spent more time on the online lab when compared to the in class one. This was because some instructions were not clear, and I would need to wait for responses from the TA instead of being able to ask questions right away. ***(More Time, Instruction Clarification, Comm. Time)***

After initial setups and troubleshooting, every lab went pretty smoothly and a tiny bit quicker than the in-class laboratories. ***(Less Time, Setup Time, Troubleshooting)***

I don't know for certain, but I would like to believe I spent more time than I would have as an in-class student. If there was an issue or I had a question, I would dedicate a significant amount of time to figuring out on my own before reaching out because of the turnaround time associated with reaching out to the TA, effectively conveying the issue, and then understanding how to fix the issue. On one hand, this caused the lab to be somewhat of a time-sink, but I believe, to use an *analogy, letting myself sink forced me to learn how to swim.* ***(More Time, Troubleshooting, Comm. Time,)***

My experience for the lab this summer was different from the other students. I did not have a Elvis board for myself, but instead I shared an Elvis board with the lab TA in his office. I was able to immediately ask the TA about any questions I had. I was able to complete the labs on pace. When I was first introduced to the Elvis board I felt that I was completing the labs slower but as the course progressed I became more diligent with my work. ***(More Time)***

It sometimes took me 8-9 hours to complete an experiment, which is way more than in-class lab students who get about 3-hour labs. ***(More Time)***

4. On average, how many times did you watch the lab instructional videos?

I watched the lab instructional videos an average of 3 times for each lab.

I watched each video around 2 times, once all the way through to understand the procedure. Then with confusion or misunderstanding, I would skim through the areas needed.

I watched all of them usually at least 2 times through. Sometimes 3.

I watched each lab video before going to the TA's office for lab. I found myself having to watch certain key parts while in Lab. The videos were helpful for describing the lab procedure document in detail.

I had to go back to the videos a lot of times. I would say more than 5.

5. How helpful were the instructors for your online laboratory experience?

The instructor, [inst. S.]*, was very helpful when it came to the online lab, he was always readily available and was good at responding to emails or texts. He was also very willing to allow us to come into his office and perform the lab procedure with him watching so we could directly ask him any questions that we had.* ***(Availability, Communication, Direct Assistance)***

The TA was imperative to the initial setup and troubleshooting technology issues that would appear with the lab materials. ***(Troubleshooting)***

[inst. S.] *was extremely helpful in making things as clear as possible and clearing up small issues with very quick turn around times considering the situation.* ***(Availability)***

Since I had the lab instructor available in-person for each lab I had great help with the labs directly. *(**Direct Assistance)***

The TA was very helpful and answered all and any questions I had. I could email him with a question at any time of the day and could expect an answer within an hour. ***(Availability, Communication)***

6. What was the greatest obstacle to completing the online laboratory?

The greatest obstacle in completing the online lab in my opinion was following the procedure without being able to ask other classmates or the TA questions about wiring the actual circuit together. ***(Procedure, Clarification)***

Since this class is condensed into a small number of weeks, having 2-3 labs a week can be a lot, but the intensity is necessary for understanding, especially in a fundamental ECE course. ***(Intensity)***

Being virtual. I feel like during in-person "normal" labs, if there is something fundamentally wrong you can grab the TA and have a face to face, live interaction where they can touch your circuit and solve "big, fundamental" issues. This was lost within the virtual lab, so it felt like if things went wrong, they went really wrong. ***(Assistance, Clarification)***

The hardest part of each lab was the report we had to write. I found the questions in the lab procedure document questions to be very involving and sometimes complex. I needed help to answer these questions sometimes, help with presenting data correctly in an application such as; Mathcad. ***(Technical Writing, Assistance, Clarification)***

I think not having the TA immediately available and doing the experiments alone was the greatest struggle. The lecture videos were very helpful as all steps of the experiment were explained in detail, but not being able to ask a question immediately can be tough. ***(Assistance, Clarification)***

7. What comments or suggestions do you have about the online laboratory experience? What can be done to improve the experience?

I would say that moving forward, the online lab could be better by simply having overly detailed procedures. I think that in person labs can get away with slightly less detailed lab procedures because there are other students and a TA readily available, I also think that this would help people become more comfortable with the EVLIS board. ***(More Detailed Procedures, Equipment)***

The lab went well, there was a few technical hurdles that had to be jumped early on in terms of getting the lab materials to work expectedly. ***(Equipment)***

I overall felt like it went well for a moderately difficult course, accelerated, and over a period where my academic inclination wasn't super high. I think the hardest thing might have been learning to not only use an o-scope, but also learning how to use the ELVIS 3 board simultaneously. We had a sit down, in person, session where we familiarized ourselves with the boards which was helpful. It might have also been helpful to have an in-person sit down where we learned about o-scopes and generators. I also learn WAY better in person, so I'm not sure that would translate to all students. ***(Equipment, Equipment Introduction, Recitation)***

I really liked using the Elvis Boards, and the only problem I had was connecting my PC to the Elvis Boards via network connection. [inst. S.] *as made a document in order to fix this issue in the future, so it should not be an issue for other students. The summer of 2023 course was shortened to 6weeks ,so we were not able to complete all the labs laid out for the course.* ***(Equipment, Troubleshooting Procedure)***

The bulleted items below are the responses from a single student in response to question 7:

- *I think the course was very well set up and organized. I can only think that having a live communication with someone, either a classmate or the TA would make the process faster.*
- *We had a fixed weekly recitation time in which we could freely ask questions. It was more focused on 212 but if there could be a session like that for 213, it would be very helpful.*
- *There could be a Canvas discussion board for 213 where anyone can put their questions and the TA could answer them there for everyone to see.*
- *Lastly, completing the 212/213 course in 7 weeks kept us all very busy. I probably spent almost all my day studying, doing assignments, and completing experiments for the duration of 7 weeks. Thankfully, the instructor and TA were accommodating with deadlines.* ***(Communication, Recitation, Student Forum, Assignment Due-Date Flexibility)***